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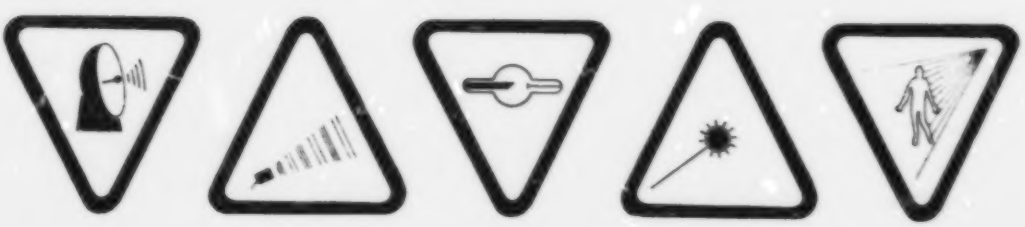

ASSESSMENT OF RADIATION EXPOSURE FOR THE PA CHEST EXAMINATION IN NEW BRUNSWICK AND PEI HOSPITALS

presented at the 8th Annual Conference of the
Canadian Radiation Protection Association
Saskatoon
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ABSTRACT

In radiation protection, comparisons are frequently made between the radiation dose received from an activity or procedure under consideration, and the dose received from a diagnostic chest x-ray. Chest radiography is by far the most frequent examination in diagnostic radiology, and with technology forever changing, there is continual need for up-to-date measurements.

There is also need for Canadian data. This paper details the results of a study conducted during the winter of 1986-87 in New Brunswick and Prince Edward Island. Skin entrance exposures for a standard man were determined using the U.S. designed and constructed LucAl phantom, at all 42 hospitals, and average effective dose equivalents assessed from the various measured beam parameters and workload statistics.

The results show a significant reduction compared with many previously reported values, and a new upper exposure limit is recommended. It is shown that the fastest film-screen combinations do not necessarily lead to the lowest patient exposures.

Introduction

During the period Dec 18th, 1986 - Mar 12th, 1987 an investigation of patient exposures for the PA(Posterior-Anterior) chest examination was made in New Brunswick and Prince Edward Island.

The projection chosen was based on the availability of a appropriate phantom and because chest radiography constitutes by far the largest fraction of the examinations in a typical radiology department. A LucAl phantom[1] consisting of 7.3 cm of plexiglas, 4.1 mm of 1100 aluminum alloy and a 19 cm airgap was used to simulate a standard 23 cm adult chest.

In 1981, Health and Welfare Canada published Safety Code RPB-SC-20A.[2] This code recommends that, for a PA radiograph of a standard 23 cm chest, the skin entrance exposure should not exceed 30 millirem (0.3 mSv). The purpose of the survey was to determine whether this was still a valid recommendation, to determine if, and how many, hospitals exceed this exposure value and, at individual hospitals, to recommend ways of minimizing radiation exposure without detriment to image quality.

All 42 hospitals and private clinics in New Brunswick and Prince Edward Island, serving a population base of 837,068 (1986 census), were inspected during the course of the survey. A breakdown of x-ray department size and average caseload is shown in Table 1. At hospitals where chest x-rays are taken in more than one room, the room having the greatest frequency of use was used for survey purposes. There was one exception, namely at Dalhousie, N.B. where a new unit was in the process of being commissioned and new film introduced.

Table 1 (Facilities)

Rooms	No. of Hosps	Av. caseload/wk
>8	5	420
5-7	3	215
2-4	18	81
1	14	25
Clinics	2	10

The facilities inspected ranged from single room departments, two with manual processing, to large modern facilities with daylight film systems and equipment dedicated solely to chest radiography. Case workload ranged from 5 to 600 per week, with the average at 110 cases per week. The combined annual total for the two provinces was estimated to be 250,000 examinations.

Data collected during the survey included kVp, mA, exposure time, SID, film and screen type and processing details. Average entrance skin exposures (ESE) were determined from a series of four exposures made at normal departmental settings. A half-layer measurement conducted at the corresponding kVp was used to determine beam quality. All kVp values were assumed to be accurate as set.

At hospitals where manual timing techniques are employed, patient entrance skin exposures can generally be calculated approximately from tube output data and current technique information. This is not possible with phototimed units; with such units the only practical method is direct measurement using a chest equivalent phantom. Nevertheless, regardless of timing method, all facilities required a personal inspection to ascertain and analyze all reasons for a particular exposure. Patient entrance skin exposure is the product of many factors such as technique (kVp, mA and exposure time), beam quality, film and screen selection, source-image distance (SID), scatter suppression, desired film density and quality of film processing, and it is impossible to determine all these remotely.

Equipment

Six hospitals were found to have equipment dedicated solely for chest radiography. These units were all operated at high kVp with long (120") focal-skin distances. The average operating kVp was 141, and the range was 130 to 145 kVp. By contrast the 37 non-dedicated units were operated on average at 84 kVp (range 65 - 125 kVp). Average tube current for all units was 245 mA (range 100 - 500 mA).

A major difference was found in beam quality between the dedicated and non-dedicated units. The average filtration of the non-dedicated units was 3.26 mm Al while the dedicated units had an average half value layer (over the lung field) of 8.9 mm Al. The high filtration of the high kV dedicated chest units arises from the use of copper filters. Rossi et al[3] showed in 1982 that a 0.32 mm Cu filter reduces ESE by 30-40% and midplane exposures by 24%, and this has now become a widely used technique. All the high kV dedicated chest units used an airgap scatter reduction technique and all, except one, compensating filters.

Most chest cassette stands were not equipped with any device or technique to reduce scatter. Only six of the 43 units had grids (14%), while 13 units (30%) used an airgap greater than 2". 26 units (60%) utilized neither airgap nor grid. Three grids had a ratio of 8:1, 2 were 12:1, while the sixth was undeterminable.

By comparison, a study conducted in the States[4] in 1984 found 72% of chest units used grids, 4% used the airgap technique, while 24% used neither.

A general rule in radiography is to employ a grid when examining areas of the body over 10 cm in thickness. The chest, with its large air cavity, has an equivalent tissue thickness of approximately this amount so the use of grids is not absolutely essential. An alternative method of scatter suppression is the airgap method.[5] Airgaps have little effect on the primary beam but they reduce the effect of scatter by increasing the distance traversed by scattered photons, and by allowing many photons to escape before reaching the x-ray film. The most probable angle of Compton scatter at diagnostic energies is approximately 50° so far more scattered photons will miss the film with a 4 or 6" airgap, than when the patient is in contact with the chest cassette.

A strong correlation was observed between the exposure control methods used and the type of x-ray equipment used for chest radiography. 16 units were three phase units and, of these, 13 used automatic exposure control or photo-timing. Of the remaining 27 single phase units only 2 used phototiming. The rest all used manual time selection.

Processing

Good processing is a vital factor in low dose/optimum contrast radiology and processor performance was assessed at each hospital using Kodak RP film, a Wejex sensitometer and RMI densitometer. Temperature was measured with a Omega digital platinum thermometer accurate to 0.05°C. There is no one single set of sensitometric parameters that can be said to correspond to optimum processing but in a well adjusted processor D_{max} should be above 3.5, average gradient in the range 2.5 - 2.8, speed point 6.1 - 6.3, and Base + Fog below 0.2. Variance from these ranges or values can be attributed to any one of a number of factors such as old film, high or low developing temperature, oxidized solutions, incorrect pH, inaccurate transport times, low replenisher rates or weak replenisher.

27 hospital processors (65%) rated good on all counts or nearly so. 55% of all processors were found to be operating within 1°C of the optimum or manufacturers recommended temperature. 18 out of the 42 hospitals (43%) visited were found to be performing some sensitometry, most on a daily basis.

Figure 1 shows the distribution of processor speeds observed amongst the 42 hospitals included in the survey. The average speed point was found to be 6.18 and the range 5.6 to 6.7. As a difference in speed point of 1.0 corresponds to exposure ratio of 2, the observed range between the fastest and slowest processors represents a patient dose differential of approximately 120%. By contrast, the LucAl pilot study[6] surveying 167 processors in the USA found a spread of 400%. A range of this amount implies that the patient exposure at each extremity is either double or half of the exposure required to obtain a film of equal density with a properly adjusted processor. It should be noted that all indices are based on a 11 point sensitometric scale.

Exposure Data

Exposure times varied from a minimum of 3.7 msec to a maximum of 96.2 msec with a mean value of 27 msec, while the minimum. mean and maximum mAs observed values were 1.0, 6.3 and 19.8 respectively. Variations in mAs settings for different units are shown in Table 2.

Table 2 (mAs)

Equipment type	Min.	Mean	Max.
3 phase units (16)	1.7	8.1	19.8
1 phase units (27)	1.0	5.7	10.4
Dedicated units (6)	4.0	10.7	19.8
All units (43)	1.0	6.3	19.8
All units (normalised to 72" SID)	0.8	4.9	10.7

Figure 2 shows the distribution of selected kVps at the 43 hospitals surveyed. With the 6 dedicated chests units, the average tube potential was 141 kVp (range 130 - 145 kVp) while the remaining 37 units had an average kVp of 84 (range 65 - 125 kVp). The average tube current was 245 mA (range 100 - 500 mA)

By comparison, in the USA six state pilot study[6] to collect exposure technique and processing data in chest radiography, it was found that more than 50% of hospitals used potentials greater than 110 kVp.

Figure 3 shows the distribution of ESE's for various operating kVp's. Not surprisingly there is no particular pattern to be observed due to the large number of variables involved. However, in the cluster around 80 kV, there does seem to be a definite trend towards lower doses with increasing kVp. Hospitals with units operating below 80 kVp and with an ESE over 10 mrem should consider raising kVp by 10 kV and halving mA. In this way, it should be possible to reduce entrance exposures without greatly affecting exit dose and level of radiation reaching the radiographic film.

Figure 3 also identifies the six hospitals that use a grid technique. Use of a grid does not necessarily result in a higher than average entrance skin exposure but certainly increases the likelihood. As so many hospitals seem able to perform successful chest radiography with a no-grid technique, it is

difficult to support the argument that the diagnostically better images justify the higher patient exposure. However, we continue to recommend that the use of grids be optional, depending on radiologist's individual choice and preference.

Figure 4 shows the distribution of entrance skin exposures based on kVp and type of unit, and Table 3 summarises the minimum, average and maximum recorded values. It is of interest to note that, although images are diagnostically far superior, high kV dedicated units do not deliver much lower exposures than low kV units, and in fact, for a given ESE, it may be shown that the total integrated doses are considerably higher than with the low kV units.

Table 3 (ESE)

Group	No. Hosps	ESE (mrem) Min.	Mean	Max.
All units	43	2.3	10.9	28.3
Grid units	6	10.0	15.3	28.3
Non-grid units	37	2.3	10.0	27.5
Dedicated units	6	4.6	9.1	18.6
NB units	36	2.3	11.5	28.3
PEI units	7	4.2	8.0	17.1

In US studies[4][6], average patient entrance skin exposures were found to be 15.6 and 20.0 mrem respectively, ranging from a minimum of 2.3 mrem to a maximum of 120 mrem. The wider use of grids, 72% and 80% respectively, would appear to be the main reason for the disparity with the NB/PEI data,

Tables 4, 5 and 6 show, in greater detail, the wide variation in entrance skin doses delivered by hospitals using similar film/screen combinations and system speeds, ranging from a low of 2.3 to a high of 28.3 mrem. Interestingly, the hospital with the minimum dose had quite acceptable processing factors of D_{max}: 3.43; Av. Grad: 2.48; SP: 6.0; B+F: 0.19 but the average film density was only 0.98. A non-grid technique was used at 106 kVp, 100 mA and the only problem was rather light films with poor contrast. This was corrected by removing 0.5 mm Al filtration.

In this report no preference is given to any film or screen manufacturer as selection obviously depends on factors such as product uniformity, desired film density and contrast, and hospitals budgets. In the case of general purpose units operating in the 80-100 kVp range, a film/screen (F/S) combination with an effective speed of around 400 is obviously the most popular, but both Tables 5 & 6 clearly show that film-screen speed is not the only important factor in low dose chest radiography. Table 5, for example, shows several low kV users giving far lower doses with a 200 speed system than others do with a 400 speed system. Without consistently good processing, optimum kVp and, possibly, use of a non-grid technique, the benefits associated with using a 400 speed system are completely lost.

For the purposes of this survey, all film-screen combinations were grouped together as either a nominal 100, 200, 400 or 800 speed system, based on

comparison with Kodak RP film and Dupont Par speed screens assigned a nominal speed of 100. In some cases it was difficult to decide which category to use, e.g. the CR7/QN3 combination may have an effective speed closer to 300 rather than 400. The variation in effective F/S speed with increasing kV and beam hardness is also an added complication. For example, a system with a true effective speed of 200 at 80 kVp may well be nearer 300 at 140 kVp.

During the survey, an attempt was made to determine true effective film-screen speed experimentally, by exposing film in a loaded cassette and determining the dose required to produce a film of unit density for the kV and beam quality used, but this proved unsuccessful due to the different cassette attenuation characteristics and the inconsistency of processing conditions.

Cassette attenuation was not addressed during this survey although it's significance in the imaging chain is not negligible. Schmidt et al[7] of the Kurt Rossman Labs in Chicago have shown that cassettes faces may have derived densities from between 1.2 and 2.7 g/cm^2 and that, with a 20 cm water phantom, carbon fibre cassettes can reduce patient exposures by amounts ranging from 28% at 60 kVp to 17% at 120 kVp. In the case of a chest with a 10-12 cm tissue equivalent thickness, obviously the effect will be much greater. Information on cassette type should therefore be included in future surveys.

Table 4 (Film/Screen Combinations)

Film/Screen Combination		Speed	No. Hosps	ESE (mrem) Min.	Mean	Max.	Av. Dens
Dupont	CR4/QN3	800	1		10.0		1.19
	CR7/QN3	400	3	2.3	5.7	10.2	1.34
	CR10/QN3	400	1		11.0		1.75
	CR10/QNFD	200	3	6.4	9.1	11.7	1.62
	CR7L/QN3	400	1		10.9		1.46
Kodak	TMG/LANEX R	400	3	4.9	8.3	11.8	1.16
	TML/LANEX R	400	1		9.3		1.51
	OC/LANEX R	400	2	7.1	8.4	9.7	1.23
	OG/LANEX R	400	5	5.8	9.7	17.1	1.41
	OG/KONICA KR	400	1		4.2		0.89
	OG/3M - A12	450	1		12.5		2.24
	RP/HI-PLUS	200	1		16.7		X
	RP/XREG	200	1		11.1		0.46
	RP/TF2	100	1		28.3		0.83
Fuji	HRG/G4	200	2	18.2	22.9	27.5	1.63
	HRG/G8	400	8	5.9	9.8	16.2*	1.24
Curix	MR4/MR400	200	4	6.3	11.9	16.8	1.57
	MR4/QN3	400	1		8.5		1.00
	MR4/XREG	100	2	6.5	12.6	18.6	1.17
	OG/ORTHOM	200	1		14.5		1.50

* with 12:1 Grid

Table 5 (37 GP Units)

Film/Screen Speed	No. Hosps	ESE (mrem) Min.	Mean	Max.	Av. Dens
800	1		10.0		1.19
400	24	2.3	9.2	17.1	1.32
200	11	9.3	14.3	27.5	1.56
100	1		28.3		0.83

Table 6 (6 Dedicated Units)

Film/Screen Speed	No. Hosps	ESE (mrem) Min.	Mean	Max.	Av. Dens
400	3	4.6	7.8	10.2	1.34
200	1		6.4		1.85
100	2	6.5	12.6	18.6	1.17

Collimation

Table 7 illustrates the high level of attention paid towards collimating the x-ray beam to the exact shape and size of the chest cassette. In only 3 cases was the beam very poorly collimated, principally due to mistaken instructions rather than poor operating procedures. There were two cases of poor alignment between the x-ray and light beams, due to mechanical problems.

Table 7 (Collimation)

Beam Area*	Rating	No. of Units
Within ± 10%	Excellent	27
±(10 - 25)%	Good	9
±(25 - 50)%	Fair	4
>50% error	Poor	3

* compared with 14"x17" (35x43cm) film

Film Density

Figure 6 shows the distribution of observed film density, recorded in most instances, as close as possible to the centre of the phantom. With a larger sample size it is expected that the curve would follow a normal distribution. Average film density was found to be 1.37, and the range 0.46 - 2.24. At both ends of this range, image quality and hence diagnostic usefulness is greatly reduced. USA data with respect to film density is very similar.[8] The acceptable range is 1.0 - 1.6 and any values outside may be attributable either to poor processing or an improper radiographic technique for a 23 cm chest.

Discussion

Using the inverse square law and tissue absorption coefficients, it can be theoretically shown that the percentage of x-ray transmission through a human chest using heavily filtered x-rays at 140 kVp and 120" SID is approximately twice that of lightly filtered x-rays at 80 kVp, 72" SID. This was confirmed by direct measurement using the LucAl phantom as shown in Table 8. Assuming intensifying screen x-ray energy conversion efficiency is independent of energy, this would suggest that ESE's with high kV dedicated chest units utilizing long SID's need only be half that of units operating at 80 kVp. Unfortunately this is not so. At high kV techniques phototimer response time becomes a limiting factor. Film/screen speeds of 400 or higher result in extremely short exposure times where millisecond errors in timing can result in under or overexposed film. For this reason, many high kVp dedicated chest units use a nominal 100 or 200 F/S speed system, and the observed ESE's are very comparable with low kV techniques.

Table 8

Transmission Factors through LucAl Chest Phantom

DECH, Fredericton (HVL = 3.6 mm Al @ 90 kVp)

KVP	ADDED FILTRATION (mm Al) (72" SID)			HEAVY FILTRATION (120" SID)
	0 mm	+1 mm	+2 mm	
60	0.04			
80	0.063	0.067	0.073	
100	0.08	0.088	0.094	
120	0.094	0.102	0.107	0.214
140	0.106	0.114	0.120	0.225

With the higher transmission factor, for any given entrance exposure, high kV techniques thus give a greater integrated dose to the patient's chest. Assuming an exponential absorption (modified slightly in practice due to the inverse square law) it may be shown that this increase is approximately 20-40%. Better image quality however normally compensates for this slightly higher patient dose.

As Table 2 confirms, exposures required for chest radiography are normally very small. With modern three phase units this normally does not present an equipment problem but, with some older units, there may be an insufficient degree of fine control available for examining different sized patients with a recommended fast film/ screen combination. Normally appropriate compensation for patient size is made by adjusting kV but if this, for any reason, is impractical or undesirable, there are a number of other possible solutions. These include increasing HVL, adding a new mA station, installing a grid, or increasing source to image distance.

Conclusions

The survey showed that the LucAl phantom serves as an excellent yardstick for assessing radiation doses from chest radiography at individual hospitals.

The average entrance skin exposures for the PA chest examination in New Brunswick and PEI hospitals was determined to be 10.9 mrem.

Of the 42 hospitals visited, ESE's at only two exceeded 20 mrem (0.02 mSv). It is recommended that this value be adopted as a new Canadian upper limit for the PA chest examination.

For hospitals using general purpose units for chest radiography, it is recommended that a film/screen combination with an effective speed of approximately 400 be used, with tube potentials not below 80 kVp. Use of 8:1 grids is acceptable. For high kV techniques, a grid or 4-6" airgap is essential and film/screen speed should be at least 200.

From workload data it was determined that, on average, each NB/PEI resident receives 0.30 PA chest examinations/year, giving an average entrance exposure of 3.25 mrem, an average midline exposure of approximately 1.3 mrem and, based on the irradiation of the lung, thyroid, breast, and bones of the rib cage, a rough whole body effective dose equivalent of 0.3 mrem/yr (0.003 mSv/yr).

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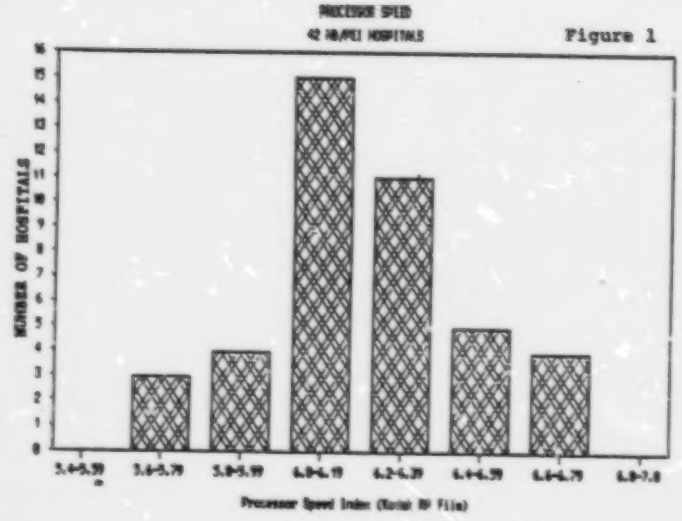

Figure 1

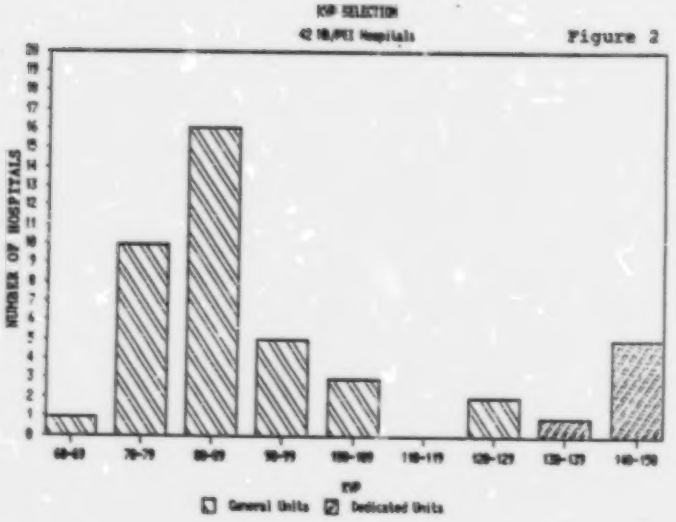

Figure 2

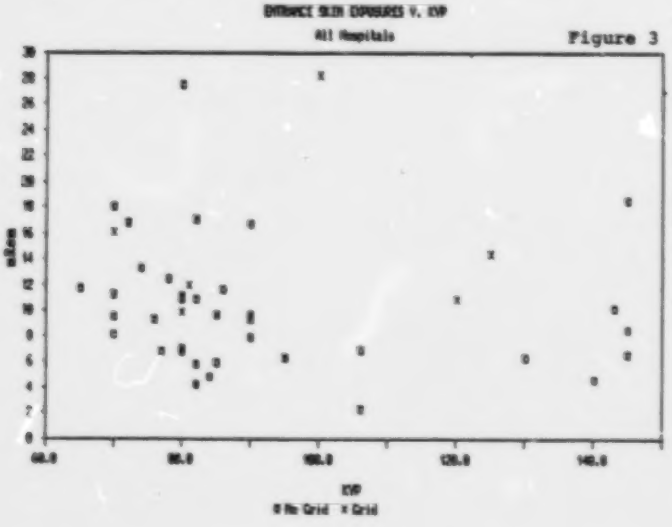

Figure 3

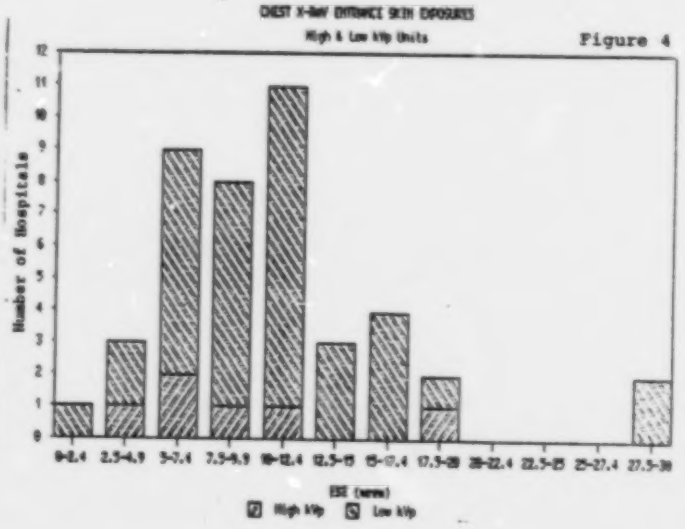

Figure 4

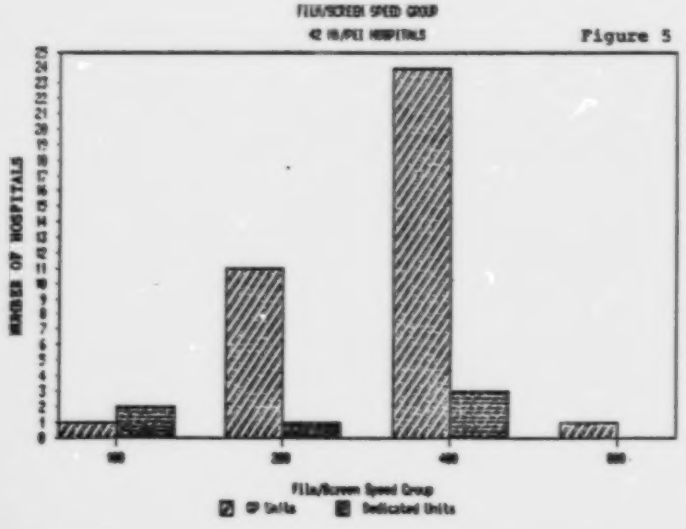

Figure 5

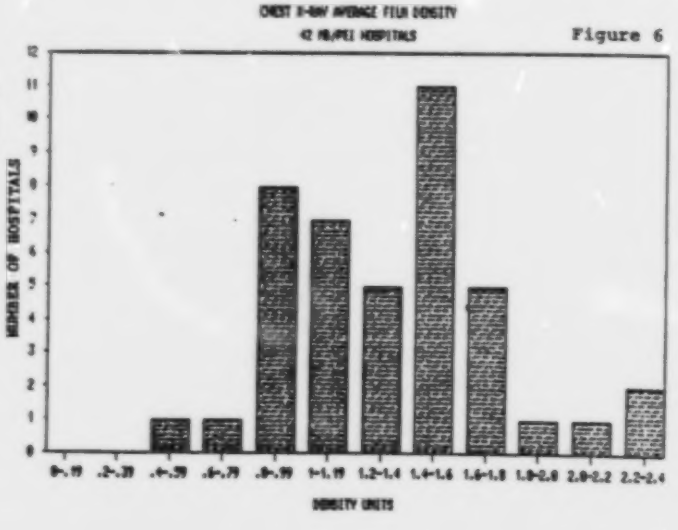

Figure 6